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The Kubota Power Synchroshift Transmission

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ABSTRACT

Normally, agricultural tractors require frequent shifting due to load changes or repetitive forward and reverse travel requirements. From the standpoint of maneuverability and workability, there is a strong demand for tractors with clutchless-transmission-operation similar to automobiles. However, power loss from the transmission is not desirable for heavy duty tractors, so should be eliminated as much as possible.

To solve this problem, Kubota, Ltd. has developed the Glide Shift Transmission (GST) which employs a power synchro shift and single clutch pack system resulting in improved maneuverability and workability while obtaining a power efficiency equivalent to that of manual gear type transmissions. The GST has been applied to the L2550DT-GST (17.5 PTO kW) and L2850DT-GST (20.1 PTO kW) farm tractors. These tractors have been marketed since 1987.

This report covers the design philosophy of the power synchro shift transmission and explains how it functions.

RECENT TRENDS have shown that improvements in maneuverability, workability and power efficiency are vital for tractor development. As a result, Kubota has developed tractors equipped with a hydraulic shuttle transmission or hydrostatic transmission (HST). This is because tractors need to change speeds frequently depending on the PTO load or axle load, or are required to repeat forward and reverse travel as shown in Fig. 1. In addition, it is more advantageous to change speeds without stopping the tractor or manually clutching.

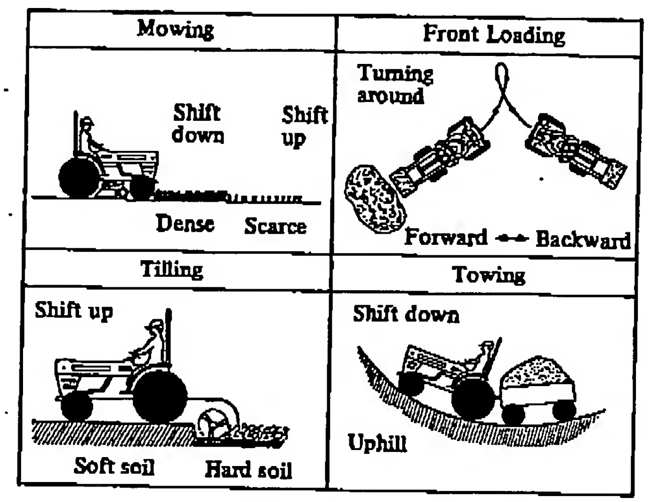

Fig. 1 Operations of Tractor

Tractor transmissions are divided into the following types such as manual gear type, partial-stage power shift, full power shift, HST and others. As shown in Fig. 2, the partial-stage power shift transmission leaves room for improvement in maneuverability because it requires manual clutching for range shifts. On the other hand, the full power shift transmission and HST leave room for improvement in power efficiency as shown in Fig. 3. Although the complex full power shift transmission features high maneuverability as does the HST, the application range is limited especially for tractors having less than 75 PTO kW due to low power efficiency. (See Fig. 4, Form of Tractor's Transmission.)

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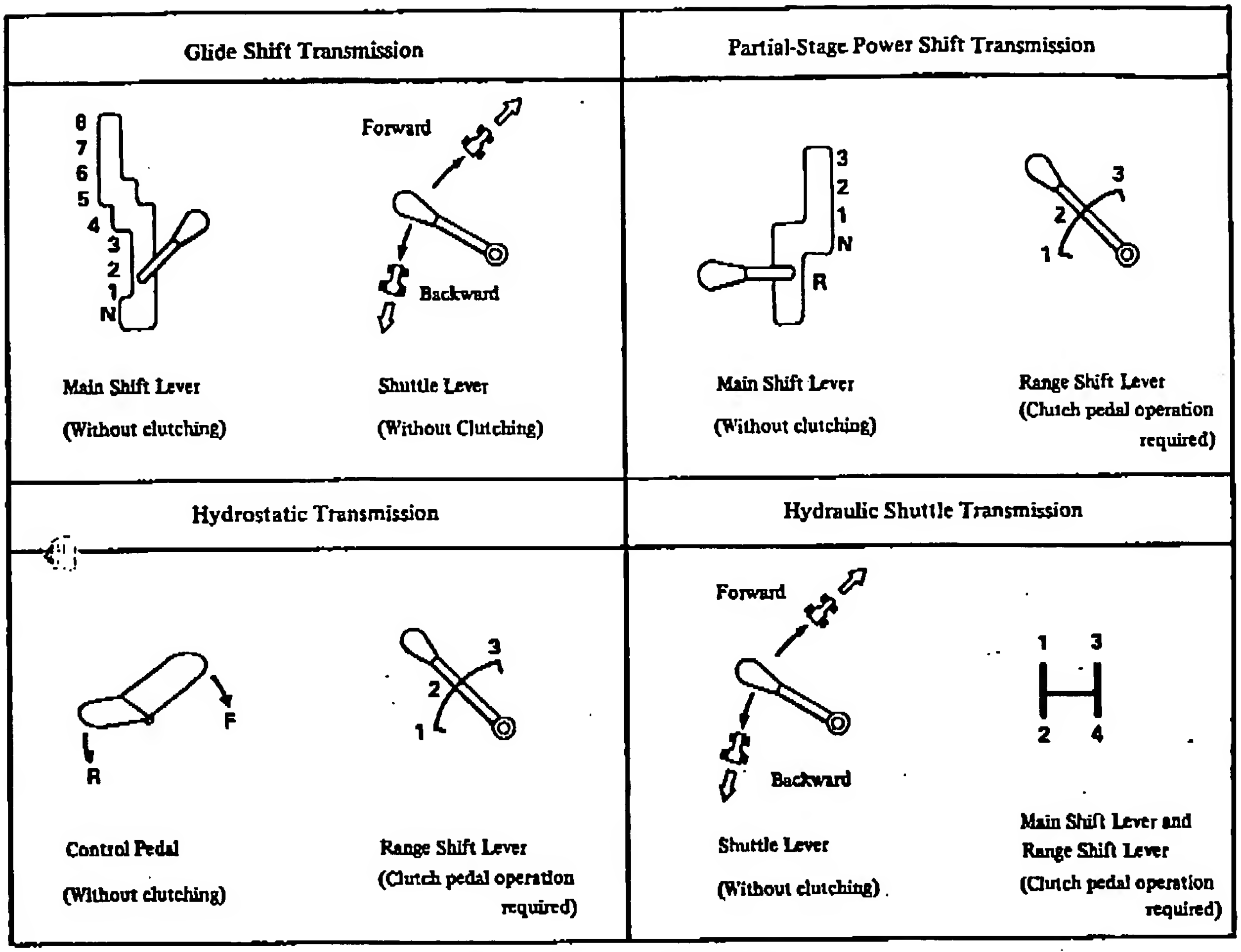


Fig. 2 Operation of Shift Lever

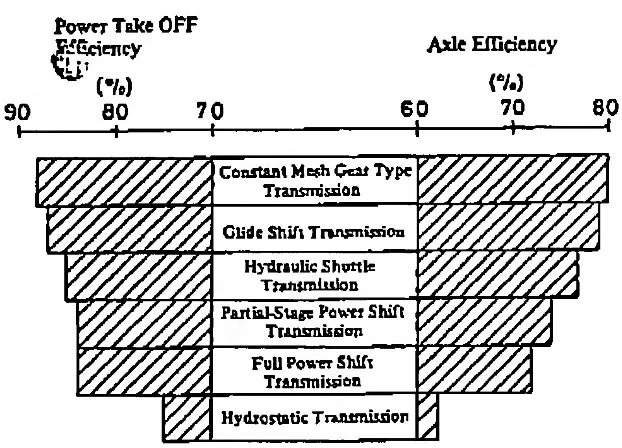


Fig. 3 Power Efficiency of Tractor's Transmission (PTO power: 15kW ~ 22kW, KUBOTA In-House Data)

Therefore, Kubota has developed the Glide Shift Transmission (GST) featuring the simple structure as shown in Fig. 5 (Cross-Section of Glide Shift Transmission). Thanks to the power synchro shift and single clutch pack system, the GST is capable of changing all speeds without clutching and is possible to deliver a power efficiency equivalent to that of gear type transmissions.

This report covers the outline of the GST and the Power Synchro Shift System designed for it.

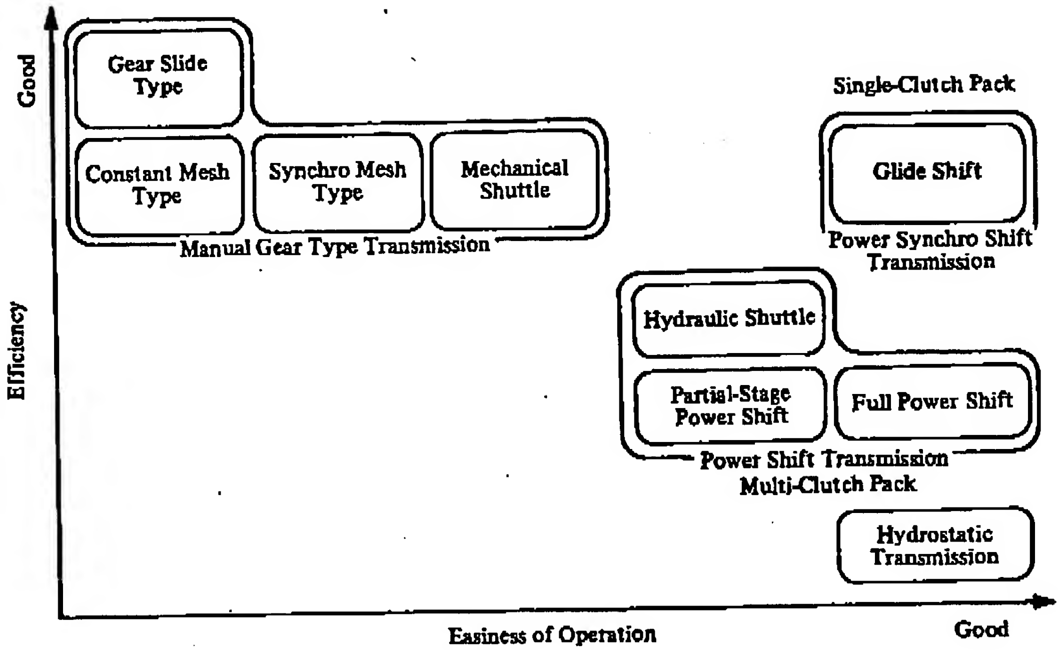
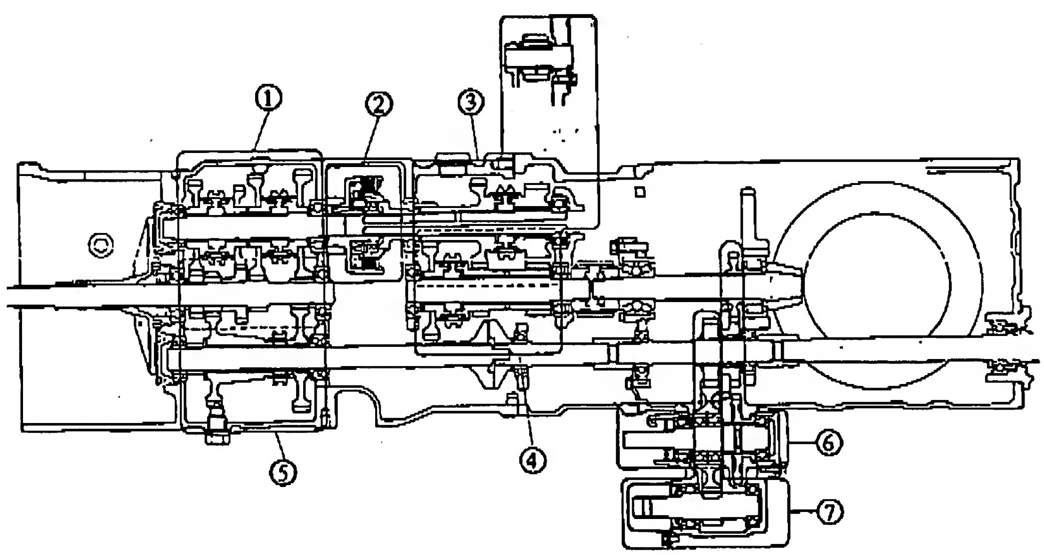


Fig. 4 Form of Tractor's Transmission



1. Main Gear Shift Section
2. Clutch Pack
3. Shuttle Shift Section
4. Hi-Lo Range Shift Section
5. PTO Gear Shift Section
6. Front Wheel Drive Section
7. Mid PTO Section

Fig. 5 Cross-Section of Glide Shift Transmission

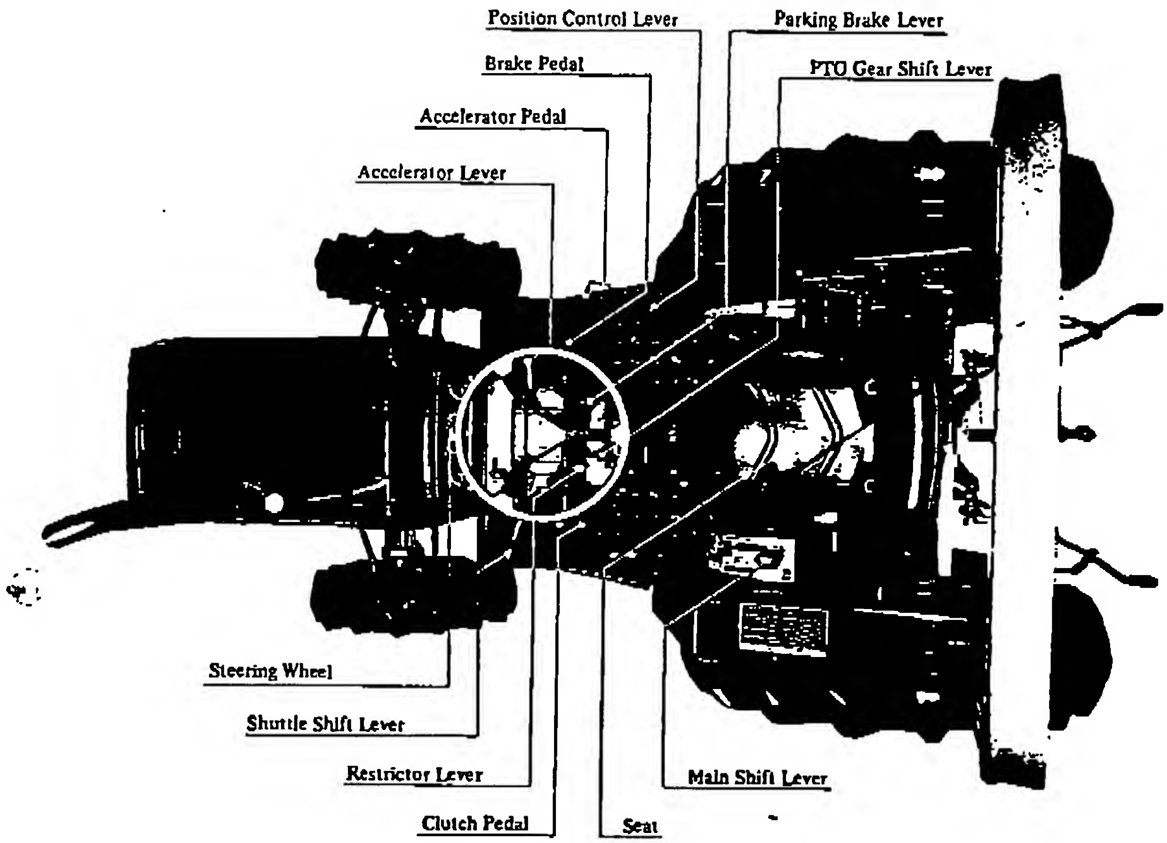


Fig. 6 Location of Shift Lever

OUTLINE OF GLIDE SHIFT TRANSMISSION

SHIFT LEVER SYSTEM (See Fig. 6.) – The main shift lever permits eight clutchless speeds between 1.6 to 21.4km/h for forward travel at 2,600 engine rpm. The shuttle shift lever allows forward to reverse shifting in all speeds without clutching. Operation of the main shift lever moves a cable that turns the rotary valve.

POWER TRANSMITTING COMPONENTS – Since the GST provides speed changes using the following single clutch pack system and power synchro shift, the power efficiency of the transmitting parts is equivalent to that of manually-clutched-gear-type transmissions.

Single Clutch Pack System – The GST uses only one clutch pack as shown in Fig. 5 which still allows eight forward and reverse speeds to be changed without manual clutching. Thus, the GST prevents the slip loss of idling clutch packs which is inevitable for multi-clutch pack transmissions. The slip loss of these idling clutch packs results in approximately 1% down in power efficiency for each clutch pack used on tractors of about 20 PTO kW.

Power Synchro Shift – The GST employs a synchromesh transmission and provides speed changes by operating each shift fork hydraulically, shown in Fig. 7. As shown in Fig. 5, the clutch pack is mounted midway between the main gear shift and shuttle shift sections in order to reduce the load to each synchronizer and provide a quick speed change.

GST HYDRAULIC STSTEM - The GST hydraulic circuit diagram is as shown in Fig. 8. The GST hydraulic system operates by letting the following valves function properly. Since the system is designed to share the same hydraulic pump with the power steering system, no special hydraulic pump is required.

As shown in Fig. 8, the GST hydraulic circuit only uses hydraulic fluid when changing the speeds of the tractor, therefore, oil drained from the three-point hitch hydraulic system is used to lubricate the clutch pack.

This system structure results in power efficiency loss from only two areas: the increased pump capacity (shown in Table 1) and the relief valve inside the oil filter bracket. This allows the GST to have similar tractive efficiency as gear type transmissions do. The power efficiency loss of the GST is only 1% less than that of gear type transmissions.

The GST hydraulic system is roughly divided into the following seven sections:

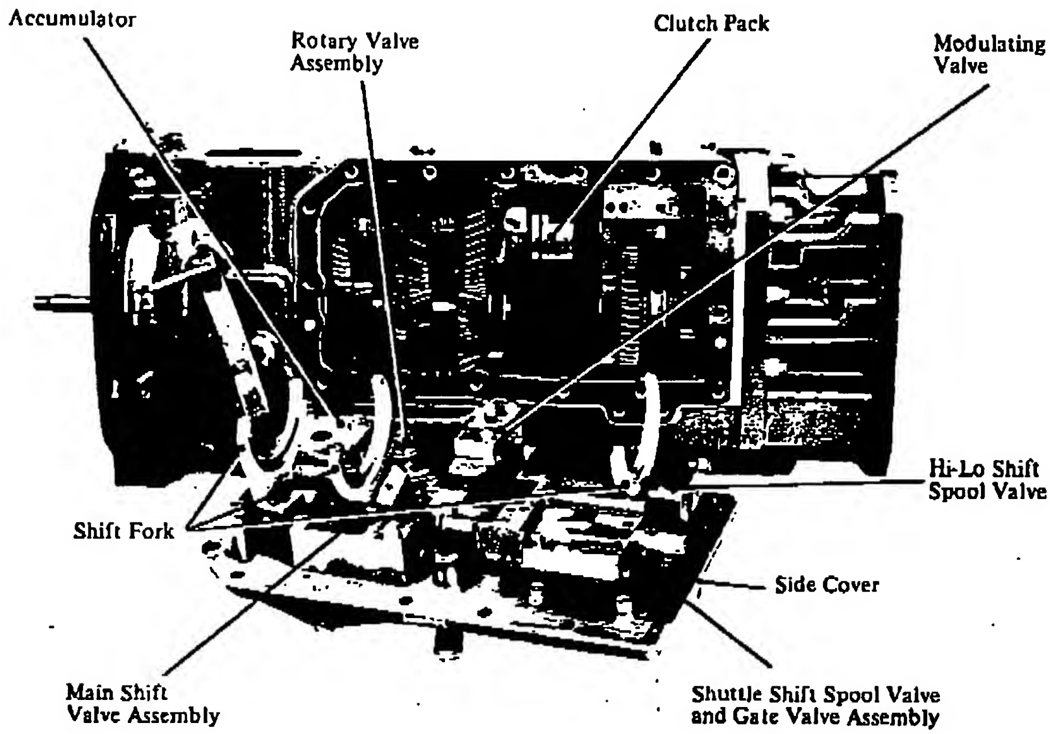
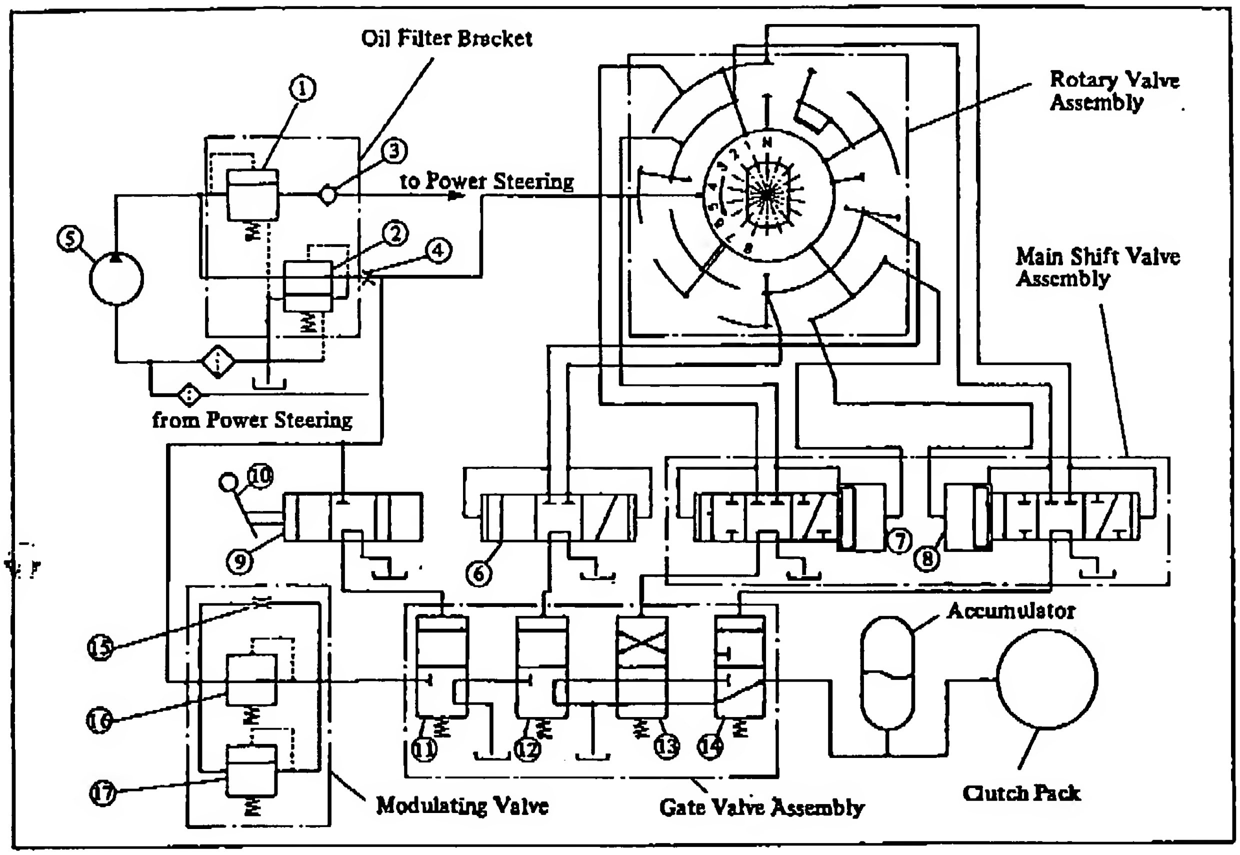


Fig. 7 Internal View of Glide Shift Transmission

Table 1 Pump Capacity

Model		L2550 DT	L2550 DT-GST	L2850 DT	L2850 DT-GST
Engine Gross Power kW		22.0	←	25.4	←
Power Take Off Power kW		17.5	←	20.1	←
Type of Transmission		Constant-Mesh Gear	Glide Shift	Constant-Mesh Gear	Glide Shift
Type of Oil Pump		Gear Type	←	←	←
Pump Capacity	For 3 Point Hitch (l/min)	24.1	31.3	28.0	31.3
	For Power Steering (l/min)	10.0	12.8	11.5	12.8



① Relief Valve
② Reducing Valve
③ Check Valve
④ System In Orifice
⑤ Oil Pump
⑥ Hi-Lo Shift Spool Valve
⑦ 3-4 Shift Spool Valve
⑧ 1-2 Shift Spool Valve
⑨ Shuttle Shift Spool Valve
⑩ Shuttle Shift Lever
⑪ Shuttle Gate
⑫ Hi-Lo Gate
⑬ 3-4 Gate
⑭ 1-2 Gate
⑮ Orifice
⑯ Low-pass Valve
⑰ High-pass Valve

Fig. 8 GST Hydraulic Circuit Diagram

1. Side Cover – As shown in Fig. 9, all oil paths are incorporated in the side cover. A steel plate is attached to the side cover with anaerobic adhesive in order to form all oil paths in the GST hydraulic system. Valves for the GST hydraulic system are mounted on the side cover. Thus, only the hydraulic pipe for providing oil pressure to the GST hydraulic system are located outside, making the structure very simple.

Fig. 9 Cross-Section of Side Cover

2. Oil Filter Bracket (See Fig. 8.) – The oil filter bracket is installed directly on the hydraulic pump ⑤. It consists of relief valve ①, reducing valve ②, check valve ③ and system in orifice ④.

Relief valve ① and reducing valve ② only distribute oil from the hydraulic pump ⑤ to the GST hydraulic system when the shift levers are used. Normally, the oil pressure in the GST hydraulic system is maintained at 2.35 MPa allowing all oil from the hydraulic pump to flow to the power steering system.

Check valve ③ is used to prevent oil pressure in the power steering hydraulic circuit from fluctuating when oil is supplied to the GST hydraulic system (during a shift).

To control the oil flow rate, system in orifice ④ is added to the oil pressure supply section in the GST hydraulic system so that the pressure of each shift valve is suitable for the synchronizers.

3. Rotary Valve Assembly – The rotary valve assembly is linked to the main shift lever via a cable.

As shown in Fig. 10, the rotary valve assembly distributes oil from the oil filter bracket to each shift spool valve according to the gear selection.

	Ports							
Speed range	Hi	Lo	4	3	n3-4	n1-2	1	2
N			o		o	o		o
1		o	o		o		o	
2		o	o		o			o
3		o		o		o		o
4		o	o			o		o
5	o		o		o		o	
6	o		o		o			o
7	o			o		o		o
8	o		o			o		o

* Items marked with "o" denote pressurizing ports and other items denote drain positions.

Fig. 10 Tractor Speed and Pressurizing Port of Rotary Valve Assembly

4. Hi-Lo Shift Spool Valve And Main Shift Valve Assembly (See Fig. 8.) – Oil pressure from the rotary valve assembly operates Hi-Lo shift spool valve ⑥, 3–4 shift spool valve ⑦ and 1–2 shift spool valve ⑧.

A shift fork is attached to each shift spool valve to operate the shifter according to the gear selected.

Right after completion of shifting, each shift spool valve permits pilot oil to be fed to the gate valve to confirm that shifting is complete.

5. Shuttle Shift Spool Valve (See Fig. 8.) – Shuttle shift spool valve ⑨ is linked to shuttle shift lever ⑩.

The shift fork is secured to the shuttle shift spool valve to operate the shifter in the synchronizer.

Right after completion of shifting, the shuttle shift spool valve permits pilot oil to be fed to the gate valve to confirm that shifting is complete.

6. Gate Valve Assembly – The gate valve assembly permits oil to be fed to the clutch pack only when pilot oil is in the shifting completion state (when pressure of all gate valves are as shown in Fig. 11.).

The gate valve assembly drains oil from the clutch pack immediately after it is released from the state shown in Fig. 11.

Shuttle Gate	Hi-Lo Gate	3 – 4 Gate	1 – 2 Gate	Clutch Pack
○	○	○	○	OFF
○	○	○	×	ON
○	○	×	○	ON
○	○	×	×	OFF

○ : Pressurizing

× : Drain

Fig. 11 Pressure of Gate Valves Prior to Clutch Pack Engagement

7. Modulating Valve, Accumulator And Clutch Pack (See Fig. 8.) – The modulating valve, accumulator and clutch pack allow the clutch pack pressure to increase gradually as shown in Fig. 12 to ensure smooth starting and changing of tractor velocity. The pressure modulation process is as follows.

First step (ⓐ → ⓑ in Fig. 12) – When the gate valves open, oil flows through the low-pass valve ⑯ to the clutch pack until the pressure reaches 0.44MPa. After the clutch pack is filled quickly with oil, the amount of oil passing through the low-pass valve decreases and the accumulator permits the oil pressure to increase gradually.

Second step (ⓑ → ⓒ in Fig. 12) – When the clutch pack pressure reaches 0.44MPa, low-pass valve ⑯ closes, permitting oil to pass through orifice ⑮ only, thus increasing the clutch pack pressure gradually.

Third step (ⓒ → ⓓ in Fig. 12) – When the clutch pack pressure reaches 1.37MPa, high-pass valve ⑰ opens, permitting the clutch pack pressure to quickly increase up to 2.35MPa.

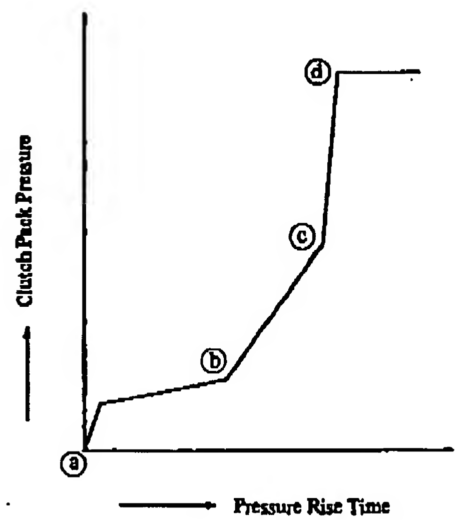


Fig. 12 Clutch Pack Pressure Raising Curve

POWER SYNCHRO SHIFT SPECIALLY DESIGNED FOR THE GST

SHIFT FLOW OF GST SYSTEM - The GST uses a single clutch pack system to change the traveling speeds. During shifting, the clutch pack is disengaged to cut torque from the drive line. If the torque is cut too long, the tractor fails to change speeds smoothly under pulling work.

To shorten the seperation time, the GST uses the shift flow shown in Fig. 13 to minimize the operation-confirmation-feedback-process which is usually done for the manually shifted transmission. The shift flow (from 1st to 2nd speed) is as follows. (See Fig. 14 and Fig. 15.)

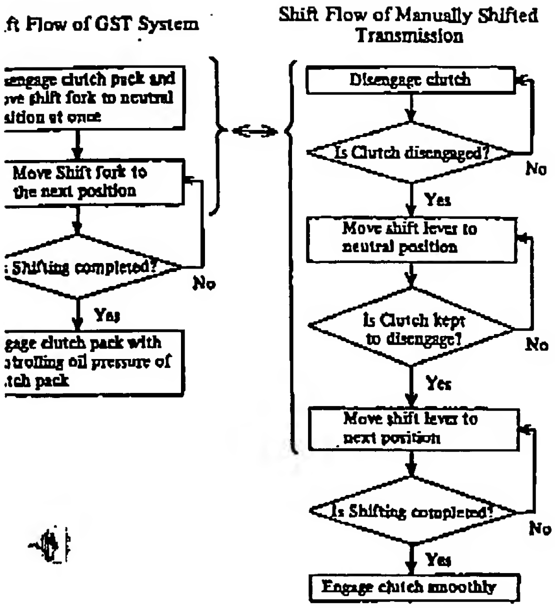


Fig. 13 Shift Flow of GST System

ep 1 of Fig. 15 – When the 1st port is pressurized as own in Fig. 14 (a) during 1st speed travel, pressure is also plied to "port to 1–2 gate valve", causing all gate valves open. The clutch pack is engaged, permitting drive power be transmitted.

ep 2 of Fig. 15 – When the rotary valve rotates from the t to 2nd position, oil drains at once from 1st port and m "port to 1–2 gate valve". The 1–2 gate valve permits clutch pack oil to drain, thereby, cutting the driving rque. At the same time, oil is fed to 2nd port, causing the 2 shift spool valve to move to the 2nd position. A drain- port is provided in the 1–2 shift spool valve as shown in g. 14 (b) so that "port to 1–2 gate valve" can drain oil ntinuously.

ep 3 of Fig. 15 – The shifter on the shift fork comes into ntact with the synchronizer ring, permitting the system enter the synchro state. At this moment, the clutch pack ist be disengaged completely because there is no way of nfirming that the clutch pack is disengaged. Therefore, 1–2 gate valve threshold pressure is set so that the itch pack pressure does not exceed the filling pressure the clutch pack during the synchro state.

ep 4 of Fig. 15 – When the shifter permits the 2nd gear engage upon completion of the synchro operation, 2nd rt is connected to "port to 1–2 gate valve" as shown in g. 14 (c), applying pressure to 1–2 gate valve. The 1–2 te valve threshold pressure is set so that the clutch pack cuit breaks as soon as pressure is applied to the valve. ien the clutch pack circuit breaks, the clutch pack pressure increases, being modulated.

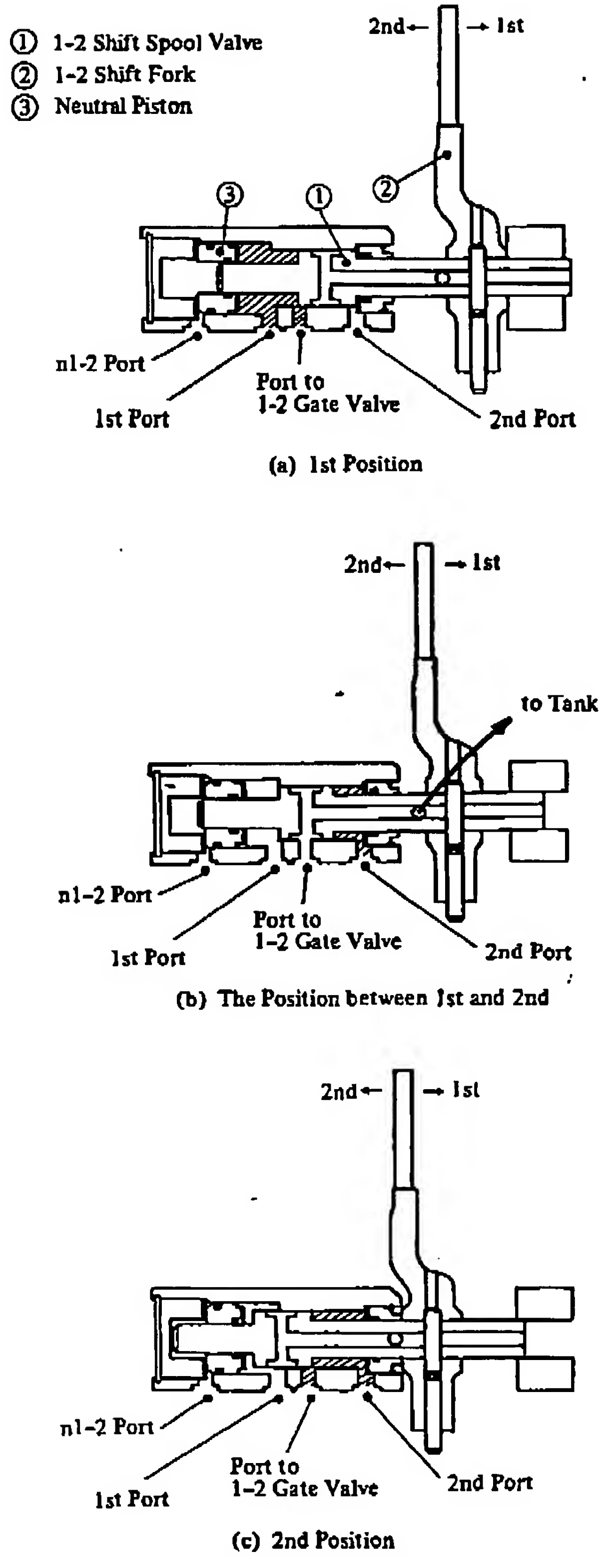


Fig. 14 Operation of 1-2 Shift Spool Valve

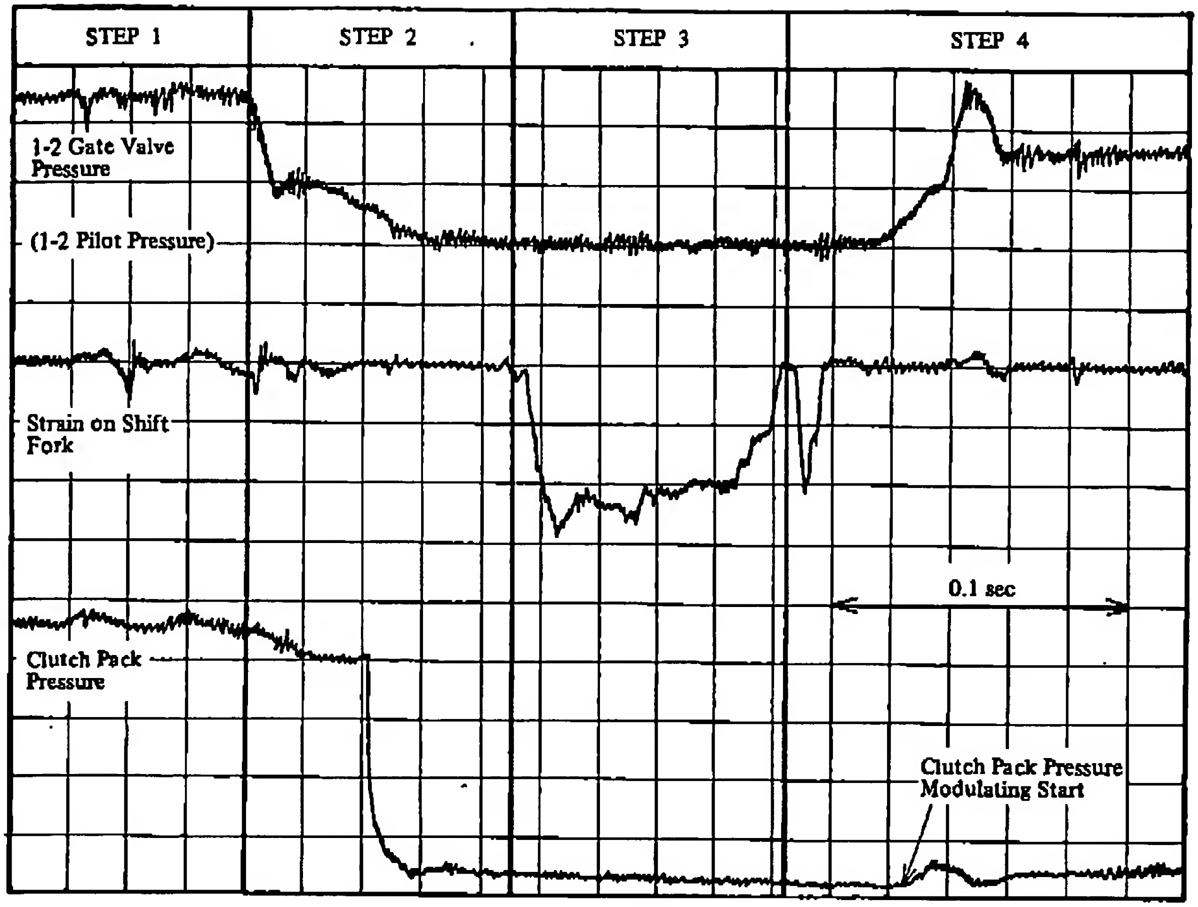


Fig. 15 Gate Valve Pressure, Clutch Pack Pressure and Strain on Shift Fork

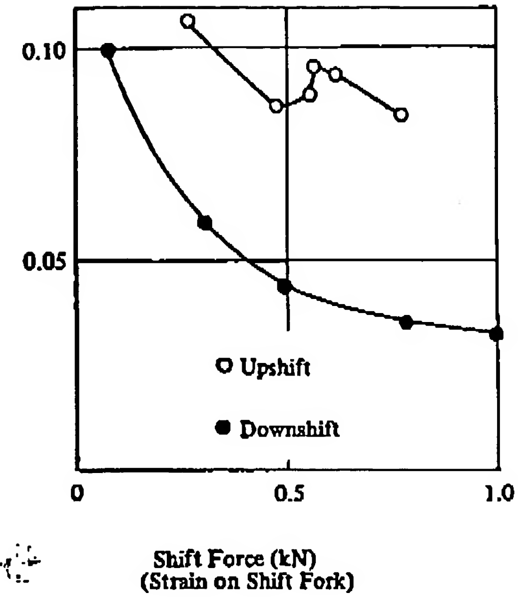
The GST system is designed so that the gears can be shifted (as shown in Fig. 13) in only 0.20 to 0.35 seconds. The shifting time including clutch pack pressure modulation time is 1.0 to 1.4 seconds, thus making smooth speed changes becomes possible.

OPTIMUM SHIFT FORCE - The GST employs a strut-type synchronizer. Namely, the chamfer of the shifter comes into contact with that of the synchronizer ring, permitting friction produced by the cone clutch to shift the gear in synchronization with the shaft.

During the synchronization process, shift force is an important factor. Too much shift force causes the chamfer of the synchronizer ring and shifter to wear excessively, resulting in gear clash. Insufficient shift force requires longer synchro time causing the tractor to stop under pulling work.

To produce the optimum shift force, a system in orifice is provided at the entrance of the GST hydraulic system. It controls the oil flow rate, which forces the oil pressure to decrease when the system begins to operate, and provides proper shift force.

Fig. 16 shows the relation between shift force (the strain on the shift fork) and synchro time, which was obtained by altering the diameter of the system in orifice. It indicates that synchro time will not change even if shift force exceeds 0.5kN. In other words, shift force more than 0.5kN results in too much force, causing the synchronizer to wear excessively. This fact indicates that a shift force of 0.5kN is suitable for the synchro specifications of the GST system.



g. 16 Relation between Shift Force and Synchro Time

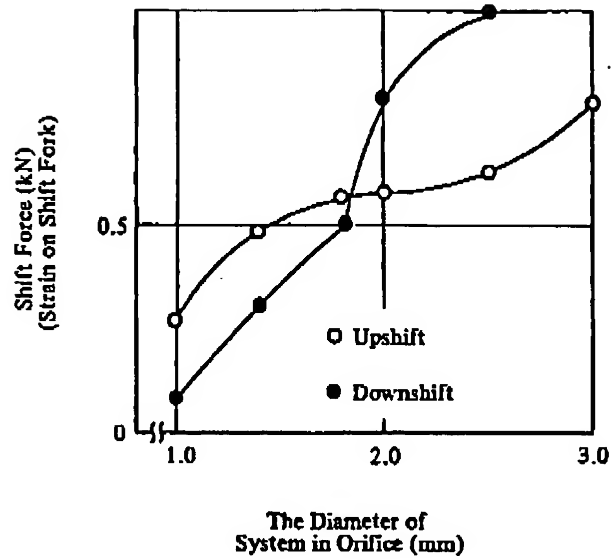


Fig. 17 Relation between The Diameter of System in Orifice and Shift Force

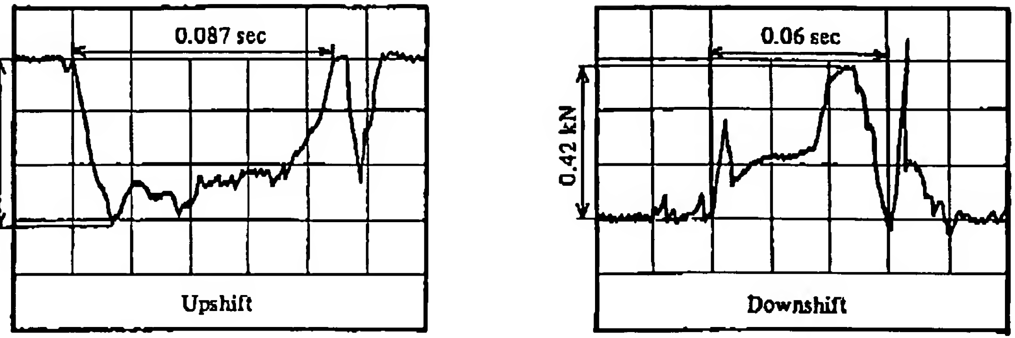
Table 2 Pressured Area and Stroke of Shift Spool Valve

	N → 1st, 2nd → 3rd Hi → Lo	1st → 2nd, 3rd → 4th Lo → Hi	Neutral Piston
1-2 Shift Spool Valve	251mm²/10 mm	192mm²/10mm	416mm²/11mm
3-4 Shift Spool Valve	251mm²/10mm	192mm²/10mm	416mm²/11mm
Hi-Lo Shift Spool Valve	299mm²/20mm	299mm²/20mm	No Neutral Piston

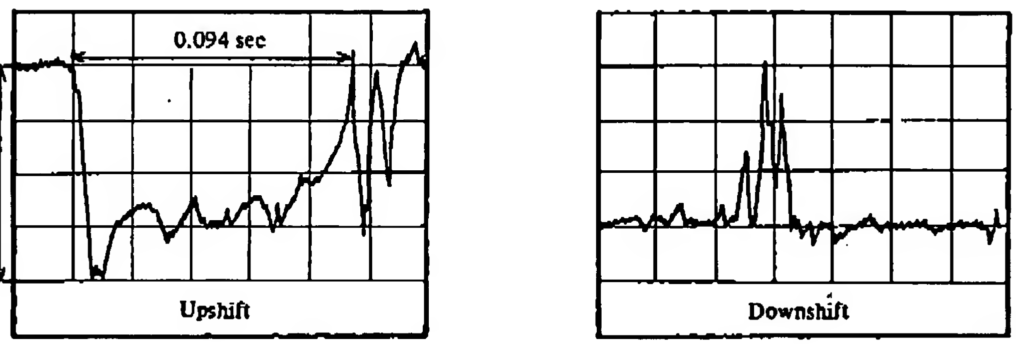
[Pressured Area (mm²)/Stroke (mm)]

Fig. 17 shows the relation between the diameter of system in orifice and shift force. It indicates that the .em in orifice diameter producing the optimum shift :e (0.5kN) for the GST shift spool valve specifications ›wn in Table 2) is 1.4mm and 1.8mm for upshift and vnshift, respectively. Therefore, the GST uses a 1.4mm-neter system in orifice to provide the synchronizer with ellent durability.

For reference, Fig. 18 shows the strain on shift fork for 1.4mm and 3.0mm-diameter system in orifices, indicating that synchro time remains little changed even when shift force is increased during a upshift. It also indicates that the 3.0mm-diameter system in orifice does not synchronize the gear, causing it to clash during a downsift.



In Case of ϕ 1.4mm System In Orifice



In Case of ϕ 3.0mm System In Orifice

Fig. 18 Strain on Shift Fork

CONCLUSION

1. The GST's special shift flow and optimum shift force have enabled gears to be shifted in an extremely short time (0.2 to 0.35 seconds), providing smooth speed change even while pulling a load.

2. Power efficiency of the GST is only 1% down compared with that of manually-shifted-gear-type transmissions, thanks to a single clutch pack system and power synchro shift.

3. The Kubota developed GST is extremely compact and is less expensive compared to full power shift transmissions. If offers similar maneuverability and workability compared to full power shift transmissions and is suitable for use on small tractors.

FUTURE PROSPECTS

Kubota plans to develop a full automatic transmission for all tractor tasks by incorporating a torque sensor and by controlling the GST system electronically.